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A Randomized Proof-of-Concept Study of Gamified Rhythmic Training in Autistic Children

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ABSTRACT

Autistic children often experience differences in rhythmic skills and executive functioning, which are associated with rhythm-related challenges and the degree of autistic traits. Training rhythmic skills could support autistic individuals, given the fundamental role of timing skills in various aspects of cognitive, motor, and social functioning. We evaluated the feasibility of rhythmic training to support perceptual, motor, and cognitive functioning by testing Rhythm Workers (RW), a finger-tapping serious game, in autistic children (ages 7–13; $n = 26$). Participants were randomly assigned to play either RW or a control game with similar auditory-motor demands over 2 weeks. Feasibility results showed high compliance (retention, adherence) and similar engagement (training duration, enjoyment, perceived difficulty) for both games. Compared to the control group, children who played RW showed greater improvement in rhythmic skills as a function of training duration and autistic traits (social awareness). Gains were also observed in composite scores of executive functioning (accuracy), though not all subcomponent tasks showed significant effects. These findings offer preliminary support for the feasibility of implementing digital gamified rhythmic training for autistic children, and suggest potential benefits for motor and cognitive engagement that warrant further investigation.

1 | Introduction

Music-based interventions have emerged as a promising approach to support individuals with neurological and neurodevelopmental conditions by engaging the brain's natural responsiveness to music. Rhythm, a core element of music, underpins motor coordination, attention, and executive functioning [1–3]. Rhythmic training using auditory stimuli—such as tapping to a beat or clapping to rhythms—has been shown to enhance rhythmic skills and cognitive functions, supporting individuals who stutter, with attention-deficit/hyperactivity disorder (ADHD), Parkinson's disease, and those on the autism spectrum [4–9, 36]. Beyond motor coordination, rhythm-based training engages beat synchronization mechanisms that rely on internal timing and predictive models [10, 11], which are increasingly involved in higher-order cognitive and social processes. Accordingly, rhythm-based interventions have been shown to support motor timing [11], cognitive functioning [12], and social communication [13]. These functions map onto core characteristics of autism, where atypical rhythmic synchronization and timing precision have been linked to social cognition and adaptive functioning [14–17]. However, intervention research on these effects remains limited and is needed to determine whether rhythm-based interventions can meaningfully support functioning in neurodevelopmental populations.

Music-based interventions have been associated with parent-reported communication and improvements in overall well-being and quality of life for autistic individuals, though their effects on cognitive and social functioning remain inconclusive [18]. Recent advances in digital health, such as serious games (games with a health-related intent), have made music-based approaches more accessible and engaging [19]. Nonrhythmic serious games have shown promising effects on emotion recognition, emotional regulation, and joint attention in autistic children [20]. However, these interventions were not explicitly designed to target rhythmic skills or executive functioning, and these domains were not assessed as outcomes. In contrast, rhythm-based training engages core timing mechanisms that support both sensorimotor coordination and higher-order cognitive control. The act of synchronizing movements to an external beat engages neural circuits underlying motor timing, attention, and cognitive flexibility [21, 22]. Specifically, successful performance in rhythmic tasks involves continuous temporal prediction, response inhibition, and error monitoring—key components of executive functioning [23, 24]. These mechanisms are thought to underlie core autistic traits such as social synchrony and repetitive behaviors [14, 25]. Notably, autistic individuals often show abnormal temporal prediction and atypical rhythm processing. These atypicalities have been linked to stronger autistic traits in motor control [25], social interaction [14], and cognitive abilities [26, 27]. Rhythm-based training, including drumming and rhythmic tasks, has been shown to engage neural circuits supporting cognitive control and attentional regulation [28–31]. Rhythmic tasks require sustained attention and temporal precision, which may bolster executive functioning components such as interference control and processing speed, which are often reduced in autism [32]. Among these, interference control is particularly relevant in autism, as it supports the ability to filter distractions and sustain goal-directed behavior [33]. In sum, rhythm-based training, by targeting both timing and cognitive mechanisms, provides a particularly promising tool for neurodevelopmental conditions, while being accessible and engaging.

In particular, rhythm-based serious games integrate structured rhythmic activities into interactive platforms, combining therapeutic exercises with motivational gameplay to promote motor and cognitive improvements via stimulation of internal timing mechanisms [34]. For example, rhythm-based games have positively affected motor functioning in Parkinson's disease [35], speech fluency in stuttering [36], and executive functioning in both typical [37] and atypical development [36, 38]. By integrating rhythmic training into digital platforms, these interventions provide an innovative, evidence-informed tool to support motor, cognitive, and social functioning in individuals with neurodevelopmental conditions. Combining principles from established therapeutic approaches with scalable, interactive technology, they offer a promising avenue to expand access to personalized support in mental health contexts.

In this study, the tablet-based game Rhythm Workers (RW) [39] was adapted to train rhythmic skills (perceptual and motor) in autistic children. Participants engaged in rhythmic tapping aligned to the beat of music with varying complexity, promoting motor timing and attentional focus through real-time feedback. The game's accessible, mobile format allowed for at-home training, supporting extended individual practice and skill transfer. This approach holds particular value for certain children on the autism spectrum who show a reduced interest in social interaction, for example, during standard behavioral interventions. Although this study focuses on autism, rhythm-based interventions have also shown promise in supporting individuals with other neurodevelopmental conditions such as ADHD and dyslexia [38, 40], where atypicality in timing and executive functioning is commonly observed [41, 42]. This investigation builds on that foundation to explore whether rhythm training can be adapted to a broader range of neurodevelopmental profiles that share similar patterns of cognitive and motor processing.

1.1 | Research Objectives and Aims

This pilot study primarily aimed to evaluate the feasibility (retention, acceptability, and adherence) of a digital gamified rhythmic training program (RW) for autistic children, using a nonrhythmic game (Frozen Bubble; FB) as an active control. The main goal was to assess whether the training protocol could be implemented remotely with sufficient engagement and compliance, including player enjoyment, perceived difficulty, regular gameplay, tapping on the screen, and completion of pre/post assessments.

As secondary aims, we examined whether playing RW led to improvements in rhythmic performance (perceptual and motor) and explored potential effects on executive functioning (e.g., inhibitory control) compared to the control group, and whether these gains varied as a function of training duration. These hypotheses were informed by a prior pilot study conducted with children with ADHD using the same protocol [38]. Finally, we explored whether individual differences in autistic traits (social awareness, restricted interests, and repetitive behaviors) predicted training-related improvements.

2 | Materials and Methods

2.1 | Participants

Thirty-one children, aged between 7 and 13 years, were initially recruited for this study from the autism community using various methods, including announcements, advertisements, and targeted outreach via social media. We specifically sought participants fluent in French or English, with 42% opting to participate in French. All participants were identified as autistic based on parental declaration; formal clinical documentation was not required. This approach aligns with the study's feasibility design and has precedent in other early stage, community-based intervention studies in autism [43]. To help ensure the integrity of parent reports, recruitment was conducted through established autism-focused organizations across Canada, in addition to open calls on social media. Furthermore, nearly all participants scored in the moderate to severe range on the Social Responsiveness Scale-Second Edition, providing converging support for the presence of clinically relevant autistic traits [44, 45]. While we acknowledge that this method does not provide formal diagnostic confirmation, it reflects real-world diversity in how autism is identified and supports accessibility and inclusion in early stage research. Exclusion criteria were coexisting neuropsychological, psychiatric, or developmental disorders associated with people on the autism spectrum (e.g., attention-deficit/hyperactivity disorder) or formal musical training (>2 years). However, comorbidities were screened based on parent report alone and may have been underreported. This limitation is particularly relevant given that autism–ADHD comorbidity is estimated to occur in approximately 30–50% of cases in the general population [46, 47], making complete exclusion based on parent report challenging. With respect to medication status, 92% of parents reported that their child was not taking any medication at the time of the study. Two children in the RW group were reported as taking medication: one child was explicitly reported by the parent as taking medication for ADHD, and one child was reported as taking melatonin for sleep.

We employed simple random sampling and targeted any Canadian parent with a child on the autism spectrum using social media advertising. This approach included anyone with a Facebook or Instagram account in Canada (~30 million users). Six male participants withdrew during the study, citing reasons such as lack of interest, technical issues, or illness, resulting in a final cohort of 26 participants (four female, one nonbinary). The 5:1 male-to-female/nonbinary ratio in this study resulted from random sampling and is relatively close to the 4:1 ratio prevalent in people on the autism spectrum [48]. Of the five participants who dropped out during the study due to lack of motivation, two were before playing the game (RW: 1; FB: 1), and three after playing the game (RW: 2; FB: 1). Upon completing the study protocol, participants received compensation of $50.

To characterize autistic traits, caregivers completed the Social Responsiveness Scale-Second Edition (SRS-2), a standardized, norm-referenced questionnaire assessing the severity and profile of autism-related characteristics in naturalistic settings. The SRS-2 yields a total T-score as well as scores across five subscales: Social Awareness, Social Cognition, Social Communication, Social Motivation, and Restricted Interests and Repetitive Behavior (RRB). The results in all five social subscales were initially explored in relation to timing and executive function measures. For clarity, we report results for the Social Awareness and RRB subscales, which showed the most robust associations in the present sample and are also theoretically linked to lower-level timing and executive processes. Social Awareness reflects sensitivity to social cues and temporal contingencies in dynamic interactions, processes that rely on perceptual timing, prediction, and attentional control rather than higher-order inferential social reasoning. Similarly, RRB has been linked to differences in cognitive flexibility, inhibitory control, and temporal predictability, all of which overlap with executive and timing mechanisms. In contrast, Social Cognition and Social Communication involve more complex representational and linguistic processes that may be less directly coupled to basic sensorimotor timing abilities, despite their relevance to rhythm-based social interventions reported in prior work [6, 13, 16]. Raw scores were used for all correlation analyses.

To contextualize how pronounced the autistic traits were in this sample, we used total T-scores, which are reported in Table 1. Although formal diagnostic confirmation was not obtained, symptom profiles on the SRS-2 indicated that nearly all participants scored in the moderate to severe range of autism-related traits. Only one participant scored at the threshold of the normal range (T = 59), suggesting that the sample was largely consistent with clinically significant presentations of autism. We assessed children's nonverbal intelligence quotient (IQ) using the short version of the Raven's Matrices [49]. Parental input was collected whenever possible, including details on their child's video gaming habits (weekly gaming time) and socioeconomic status. Socioeconomic status was assessed using parent-reported household income and education level. Video gaming habits were also measured to characterize prior gaming experience. Randomization resulted in comparable groups on these variables at baseline, reducing the likelihood that post-intervention differences reflect pre-existing gaming experience or socioeconomic factors rather than the intervention. Prior gaming experience can influence sensorimotor skills [50], while socioeconomic status affects access to cognitive support and overall mental health [51–54]. Given the small sample size of this study, nonparametric Wilcoxon rank sum tests were used for group comparisons of participant characteristics. Further details on demographics and background characteristics are presented in Table 1. Drawing from a meta-analysis on music training and inhibition control, we anticipated a medium-to-large effect size [31]. With 80–90% power at a 5% significance level, a sample size of 13–15 participants per group was deemed sufficient for a proof-of-concept study. For confirming causal inferences, broader generalization, replication, and more advanced statistical analyses, a larger sample size and extended training duration are suggested. The study was approved by the Institutional Review Board of the University of Montreal (CEREP-20-008-P). Prior to participation, written informed consent was obtained from the parents or legal guardians of all participating children. In addition, children provided verbal assent before completing the study procedures.

2.2 | General Procedure

Participants were randomly assigned to the experimental training group (the rhythmic game) or the active control group (the nonrhythmic game) using covariate adaptive randomization with the minimization approach [55] by an experimenter who was not involved in any other task during the protocol execution. The first six participants were assigned via block randomization (random permutation of 3 in the experimental group and 3 in the control group) without regard to covariates. The seventh and eighth participants received purely random assignments. The remaining participants were then assigned using biased coin randomization with $p = 0.80$ [56] to minimize group imbalance in the number of participants, gender, age, language (English/French), and music experience. These variables were group-matched at $p > 0.89$ in the final sample. Biased coin randomization is a technique used in clinical trials to balance participant allocation across treatment groups by increasing the likelihood of assigning participants to the smaller group when imbalances arise, ensuring more even group sizes and reliable comparisons, especially in smaller trials. The research followed a double-blind, two-arm, parallel-group randomized active control design, in which children and parents were informed that the study compared two music-based games designed to be played on a tablet and to support attention and cognitive skills, without emphasis on rhythm or timing-specific hypotheses. For information on the procedure, see the CONSORT statement, checklist, and flow diagram (Figure 1).

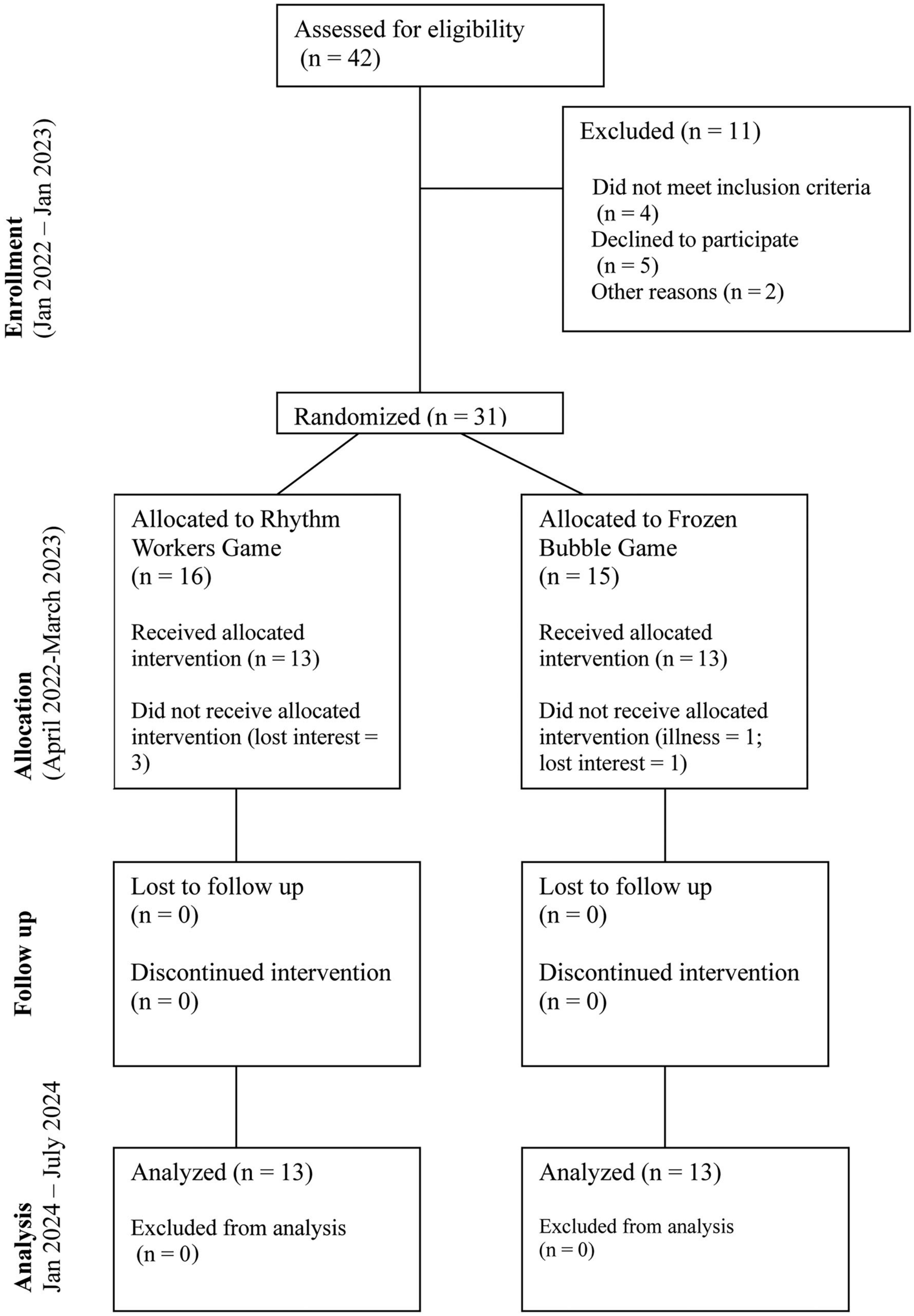

FIGURE 1 | CONSORT diagram showing the flow of participants through each stage of the randomized control trial.

TABLE 1 | Participant background and performance baselines.

Characteristic	Rhythm Workers					Frozen Bubble					*p*
	N	**Mean**	**SD**	**Min**	**Max**	***N***	**Mean**	**SD**	**Min**	**Max**	
Age (years)	13	11.0	1.6	8.3	13.0	13	10.7	1.7	8.0	13.4	0.59
SRS-2 (total T-score)	12	69.1	6.0	59.0	79.0	13	72.5	5.7	62.0	82.0	0.19
Nonverbal IQ (standard score)	13	98.1	15.9	67.0	118.0	13	98.1	9.2	85.0	113.0	0.80
Weekly gaming time (min)	11	979.1	574.0	90.0	1800.0	9	1060.0	815	150.0	2250.0	0.91
Parent education	10[a]					9[a]					0.20
High-school degree			0 (0%)					1 (11%)			
Professional certif.			0 (0%)					2 (22%)			
Bachelor's degree			6 (60%)					5 (56%)			
Graduate degree			4 (40%)					1 (11%)			
Household income	10[a]					9[a]					0.40
< $25,000			0 (0%)					1 (11%)			
$25,000–$49,999			0 (0%)					1 (11%)			
$25,000–$50,000			0 (0%)					1 (11%)			
$50,000–$74,999			1 (10%)					0 (0%)			
$75,000–$99,999			3 (30%)					3 (33%)			
≥ $100,000			6 (60%)					3 (33%)			

[a]Not all parents consented to the sharing of this information.

The study was conducted entirely remotely. All outcome measures, including the Raven's Progressive Matrices, were administered virtually via secure video conferencing. During each session, participants shared their screens and were monitored by a trained research assistant to ensure compliance. Tablet devices with a preinstalled allocated serious game and tests for rhythmic abilities were mailed to families with instructions. This remote design allowed participation across Canada while preserving standardization of test administration. Importantly, the study was conducted during the COVID-19 pandemic, when in-person testing was not feasible, further underscoring the need for accessible, home-based assessment protocols. For further details on procedures such as screening, remote testing and training, stimulus selection, randomization, equipment, calibration, and game scoring, see the ADHD protocol study [38].

2.3 | Training Protocol

Participants were asked to play their designated game for 30 min daily, 5 days each week, over 2 weeks (totaling 300 min of gameplay). They had the flexibility to consolidate two 30-min sessions into a single 1-h session for better scheduling convenience. Clear instructions were provided: "I would like you to play the game for about 30 min a day, five days a week, for 2.5 h a week. You can play more if you want, but don't play more than an hour a day." None of the participants reported surpassing this 1-h daily limit. Participants were prompted to complete a pre- and post-session questionnaire throughout the 2-week gaming period. This questionnaire featured nine binary questions concerning their mood, derived from a children's mood assessment [57]. Additionally, participants indicated their game progress (level number) and assessed the game's perceived difficulty using a 5-point Likert scale (1 = very easy; 5 = very hard), along with rating their enjoyment level (1 = very boring; 5 = very fun). To monitor gameplay fidelity, a research assistant contacted parents every 3 days to ask whether any assistance was provided or required for the study. Parents were also encouraged to share open-ended feedback about the session. Across all participants, only two parents reported providing minor motivational support. Families were informed that their eligibility and compensation were not dependent on performance or independence, to encourage honest reporting. The application automatically logged detailed session data (e.g., timestamps, number of taps, level progress), and these data closely matched parent-reported logs upon visual inspection, supporting the accuracy of gameplay reporting. All testing sessions were conducted via live videoconferencing. During tasks, the experimenter maintained continuous audio and video contact with the child to monitor task engagement and confirm that responses were provided by the child without assistance from caregivers. For rhythm-based tapping tasks, families were provided with a flexible phone holder that allowed a secondary camera (smartphone) to be positioned to clearly capture the child's hands while tapping, independently of the device running the task. This setup enabled real-time visual verification of the child's responses and ensured that caregivers were not physically assisting during task performance; for further details, see the prior protocol validation study [38]. While remote testing cannot entirely eliminate the possibility of off-screen assistance, continuous audiovisual monitoring substantially reduced this risk and aligns with current best practices in supervised virtual behavioral testing [58–60].

2.4 | Outcome Measurement Procedures

All assessment and outcome measures were administered remotely due to the home-based design of the study. Participants completed cognitive and motor tasks using their home computers via secure video conferencing platforms (e.g., Zoom or Microsoft Teams). Prior to each session, research assistants verified internet speed and technical compatibility to ensure consistent task performance. Executive function tasks were administered using computer-based protocols (e.g., Flanker, N-Back, and Go/No-Go) and supervised live via screen sharing, allowing researchers to monitor compliance and task engagement in real-time. Rhythmic task measures were collected using a tablet-based tapping application with millisecond-level precision [61], and data were automatically logged by the system. Parents were instructed not to assist their child during task performance, and all sessions were scheduled at convenient times for participants.

2.4.1 | Rhythmic Serious Game

This proof-of-concept study featured RW, a serious game initially designed for adults [39]. Although the scoring method and synchronization conditions remained consistent with the original version, notable enhancements were implemented in the visual presentation, gameplay dynamics, difficulty levels, and musical elements to cater to a younger audience. This version of RW was a noncommercial, research-only prototype developed independently for academic purposes. No financial or material support was provided by the company producing the game (BeatHealth), and the game used in this study is not available for sale or clinical use. The design, implementation, and analysis of the study were conducted by the research team entirely independently of the company. For details on these changes, refer to the protocol validation study [38]. In this iteration of RW, the participant's task was to synchronize their finger taps to the beat of musical snippets. Each of the 32 levels had a unique musical excerpt with a fixed tempo. The player's primary objective was to construct a building by matching the taps with the musical beat. For more information on scoring, see the previously described game protocol design [38, 39]. Figure 2A is an illustration of gameplay in the RW game.

For illustrative purposes, a sample of the musical stimuli used in the game, along with gameplay examples, can be accessed via the following link: https://osf.io/4twz7/?view_only=ab2a296d13974319b500fd2b94e2e726.

2.4.2 | Nonrhythmic Active Control Game

The FB game was used as a control condition and was adapted from an open-source version available on GitHub (https://github.com/videogameboy76/frozenbubbleandroid). It is a puzzle arcade shooting game that consists of eliminating colored bubbles by aiming and tapping with a finger on the touchscreen. The arrangement of bubbles gradually descends, and the game concludes if the bubbles reach the bottom of the screen. Players are tasked with connecting bubbles according to their colors. The connected group detaches and falls upon connecting three or more bubbles of identical color, freeing any bubbles bound beneath them (refer to Figure 2B). Although the two games differed in the exact visual style, a separate study [38] evaluated the aesthetic quality of both RW and FB in a comparable pediatric sample (ages 7–12 without neurodevelopmental disorders). Children rated both games similarly in terms of visual appeal and engagement, suggesting that graphic differences are unlikely to have biased compliance or outcome differences. The FB game also included background music; however, participants were not instructed to synchronize their movements to the music, and task success did not depend on temporal alignment with auditory stimuli. To partially equate musical exposure across conditions, the same set of 32 musical excerpts used in RW was presented in FB in randomized order. However, musical parameters (e.g., volume level and beat saliency) were adjusted so that music functioned as background rather than as an explicit synchronization cue. Thus, although both conditions included auditory stimulation, only the rhythmic training condition required active beat alignment.

2.5 | Evaluation of Game Compliance and Acceptance

The primary objective of this proof-of-concept study was to assess whether participants adhered sufficiently to the study protocol and engaged similarly with both the experimental and control games.

2.5.1 | Adherence, Compliance, and Game Acceptance

Adherence was calculated by dividing the number of participants who completed the study (all testing and returned equipment) by the number of participants who were randomized. The target for adherence was set at 70% as per the expected rate in interventions in pediatric populations with mental health diagnoses [62]. We evaluated participant compliance by calculating the total training duration (incorporating both self-report and device-logged sessions) and cumulative playing time (the time spent in active gameplay logged on the device). Participant-provided session times and dates were manually cross-referenced with log files to ensure consistency.

Within the scope of this study, game acceptance was assessed by ratings of enjoyment and perceived difficulty following gaming sessions, as well as overall recommendations for the game. In the analysis, positive responses were defined as both "yes" and "maybe with changes," reflecting participants' general support with or without modifications. See the ADHD protocol study for more details on how these tasks were designed; refer to the protocol validation study [38].

2.6 | Evaluation of Game Training Efficacy

Our secondary aims were to test whether RW improved rhythmic and executive functioning outcomes relative to the control group, and whether effects scaled with training duration.

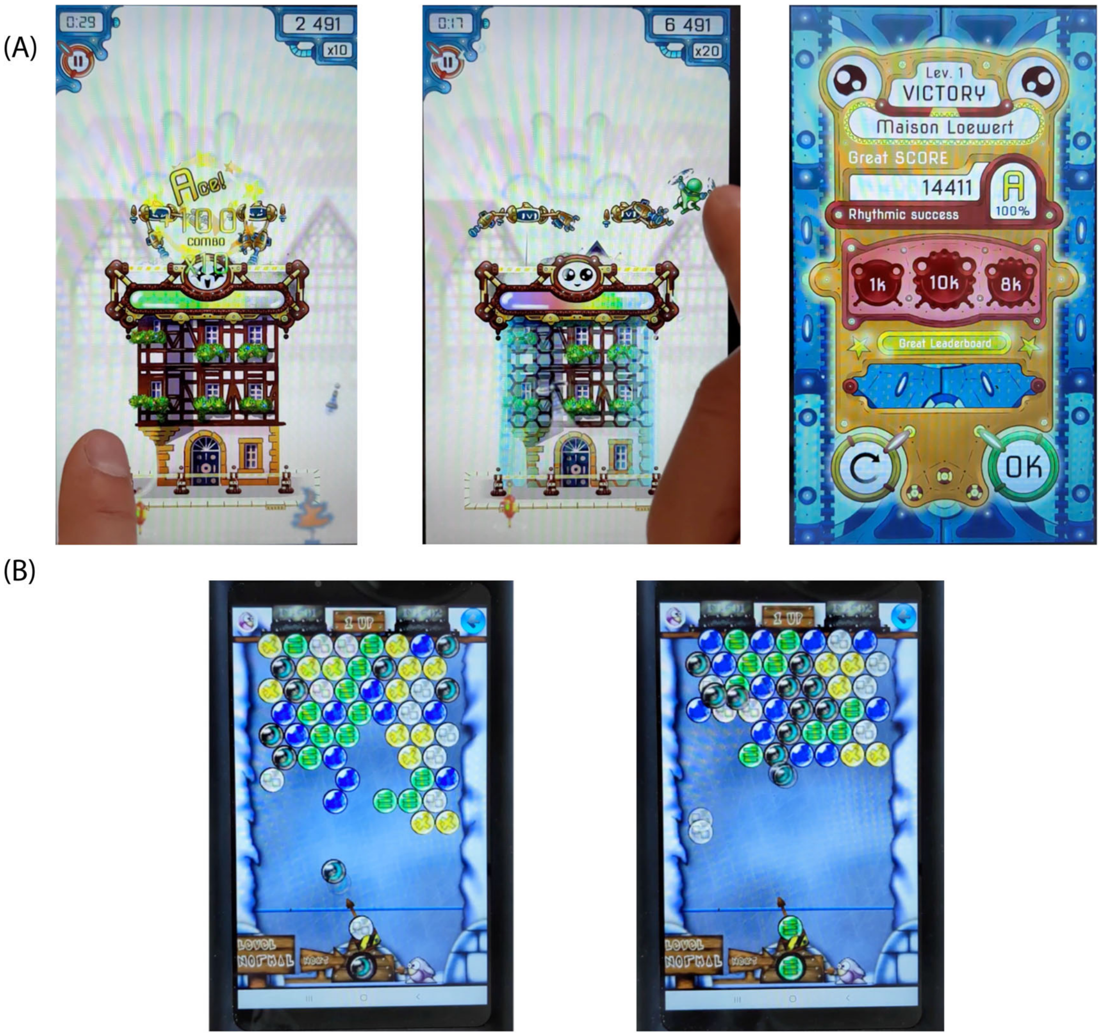

FIGURE 2 | (A) Illustration of gameplay in the Rhythm Workers (RW) game (experimental training condition). The player built a structure on the left side, earning total points and receiving feedback. In the middle, they tapped on a moving visual target in time with the beat. On the right, they checked their score once they finished the level; (B) illustration of gameplay in the control game, Frozen Bubble (FB). To the left, a black bubble was launched toward the upper pair of black bubbles following two sequential finger taps—the initial tap was to arm and the subsequent tap was to direct the shot. On the right, at a different point in the game, a bubble was successfully striking its target, causing additional bubbles to detach.

2.6.1 | Assessment of Rhythmic Abilities

We evaluated rhythmic abilities using perceptual and production tasks from the Battery for the Assessment of Auditory Sensorimotor Abilities (BAASTA) [61, 63], which has been previously used in developmental populations, including children with developmental disorders [39, 41]. These tasks test the capacity to extract the beat in a perceptual task (i.e., accuracy in the Beat Alignment Test) and the variability in aligning movement to an auditory beat (i.e., synchronization consistency in the finger tapping tasks—tapping to a steady metronome and to music). For details on how these tasks were designed, refer to the ADHD protocol study [38] and the Supplementary Materials for a summary table of the constructs measured.

2.7 | Assessment of Executive Functions

We administered set-switching, Eriksen flanker, and Go/No-go tasks to examine executive functioning. For details on how these tasks were designed, refer to the ADHD protocol study [38] and Supplementary Materials for a summary table of the constructs measured.

2.8 | Measures and Statistical Analyses

We performed all statistical analyses using R Studio [64].

2.8.1 | Compliance and Acceptance

We employed the Wilcoxon rank sum test to assess and contrast the averages of both games regarding compliance and acceptance metrics due to our anticipation of non-normally distributed data for these measures.

2.8.2 | BAASTA

We used A-prime (A′) instead of d-prime to assess perceptual beat tracking sensitivity (BAT), as A′ provides a more stable sensitivity estimate in cases of high performance and small sample sizes. A′ is less sensitive to extreme values in hit and false alarm rates and avoids the normality assumptions of d-prime, making it particularly useful when performance is high, and sample sizes are small [65, 66]. This ensures a more robust sensitivity measure, keeping scores within realistic bounds. For paced tapping tasks, synchronization consistency was evaluated using logit-transformed vector length values [38]. These values were converted to z-scores based on the pre-training mean and standard deviation for each subtask, then averaged per participant and time point to derive standardized scores for both metronome and music-paced tapping. The Beat Tracking Index (BTI) was computed to capture combined perceptual and production abilities. This composite score was chosen for its high test-retest reliability [61, 63], its effectiveness in identifying individual differences in neurodevelopmental disorders like ADHD [41], and because it successfully captured improvements of rhythmic abilities in previous remote testing protocols involving children with neurodevelopmental conditions [36, 38]. In the present study, the BTI was calculated as the mean of three equally weighted standardized components: perceptual sensitivity (BAT A′), synchronization consistency to a steady metronome, and synchronization consistency to music. Each component contributed one-third of the composite score. This weighting was selected to equally capture transfer effects across perceptual and sensorimotor timing contexts, rather than to optimize diagnostic sensitivity as in beat-deafness screening applications.

To evaluate changes in rhythmic performance (BAASTA outcomes; post-training minus pre-training) between each game, we used linear modeling with the lm() function in R for metrics including BTI, paced tapping to music, paced tapping to metronome, and BAT A′. The dependent variable in each model was the difference in scores between time points, representing post-training minus pre-training performance. Given the high variability in cumulative play time, a mean-centered term for cumulative play time was included to adjust for its influence on improvement. We also included a mean-centered term for the degree of autistic traits (SRS-2 total T-scores) to account for trait-dependent variability. The models used the following predictors with all interactions (two-way and three-way): Difference score = 1 + Game Played * Cumulative Play Time * Degree of Autistic Traits. Eta-squared effect size interpretations were based on Ref. [67]. Additionally, individual differences in training dosage (cumulative play time) were assessed within each group separately in relation to rhythm scores using Kendall correlations. The SRS-2 scores were used to measure the influence of autistic traits on secondary and exploratory outcomes. When used in mixed effects models, SRS-2 T-scores were scaled and included as a standardized term to index the global autistic trait. In the context of exploratory correlations between change scores (BTI; executive functioning accuracy index) and SRS-2 subdomains (Social Awareness, Motor Skills, Restricted Interests, and Repetitive Behaviors), we used raw scores to preserve variability at the subscale level. Primary analyses for rhythmic and executive outcomes were conducted on single composite scores (BTI and executive functioning index) and, therefore, did not involve multiple parallel comparisons. Follow-up analyses of individual task components and SRS-2 subdomains were exploratory and are interpreted cautiously.

2.8.3 | Executive Functioning Tasks

In the Flanker and Set-Shifting tasks, response times (RTs) were calculated after removing incorrect or premature responses. RTs below 200 ms were excluded, but no maximum threshold was set to capture the full performance range. Following prior studies using the Trail-Making Test, we calculated proportional scores from RT values as a sensitive measure of change in executive functioning after intervention [68, 69]. The proportional score was computed as (Congruent RT − Incongruent RT)/(Congruent RT), where higher (less negative) scores indicate better attentional functioning. This formula differs from the typical approach by reversing the numerator, allowing higher values to represent better performance and improvement after training. For the Set-Shifting task, we calculated the difference between the proportional RT of nonmixed task blocks (only location or direction rule) and the mixed section (alternating rules). For the Flanker task, we computed the difference between the proportional RT of congruent and incongruent trials. The same procedure was used for calculating the proportion of correct responses. In the Go/No-Go task, scoring was based on signal detection theory to assess sensitivity in detecting Go stimuli, considering response bias. A′ was used as the nonparametric measure, where a value close to 1.0 indicates high discrimination sensitivity.

We combined performance across these tasks into a single executive functioning index, reflecting the interdependencies of cognitive flexibility, inhibition, and rule-switching according to Diamond's Integrated Theory [70]. This composite index was based on accuracy scores from the Go/No-Go, Flanker, and Set-Shifting tasks, and a combined reaction time score using proportional z-scores for Flanker and Set-Shifting tasks. Improvement was calculated as the difference between post- and pre-training scores. Gains were evaluated using the Wilcoxon rank sum test, given the exploratory nature of the analyses. The impact of individual differences in training dosage was assessed through Kendall correlations between rhythm scores and continuous play time within each game. Additionally, we explored the relationship between changes in the executive functioning index for accuracy and baseline degree of autistic traits using the SRS-2 global standardized and subdomain scores.

2.9 | Data Availability and Process Transparency

All data generated or analyzed during this study are available upon reasonable request by qualified researchers. The underlying code for this study is not publicly available but may be made available to qualified researchers on reasonable request to the corresponding author. To support clarity and precision in written expression, the authors used ChatGPT [71] to assist with refining the wording of certain passages. The tool was used strictly for language enhancement, and all substantive content and interpretations remain the responsibility of the authors.

3 | Results

First, we present the results of compliance and acceptance of both games in autistic children, followed by the effects of RW training on rhythmic and executive functioning.

TABLE 2 | Compliance with protocol targets and acceptance for the two serious games.

Characteristic	Rhythm Workers					Frozen Bubble					*p*
	N	Mean	SD	Min	Max	*N*	Mean	SD	Min	Max	
Cumulative play time	13	188.7	78.5	69.0	318.3	13	280.9	109.6	47.0	520.9	0.014
Taps per minute[a]	13	55.7	8.8	34.3	65.8	13	58.5	12.9	36.2	80.5	0.61
Game enjoyment	12	3.1	0.6	2.0	4.0	12	3.5	1.0	1.7	4.6	0.23
Perceived diff.	12	3.1	1.0	1.9	4.9	12	2.6	0.5	1.4	3.2	0.67
Recommend[b]	11					11					0.49
"Yes"			*n* = 2 (55%)					*n* = 6 (55%)			
"Maybe with changes"			*n* = 7 (18%)					*n* = 2 (18%)			
"No"			*n* = 2 (17%)					*n* = 3 (27%)			
Did not answer			*n* = 1					*n* = 2			

[a]Total number of logged finger-taps by game divided by total training duration (including menu navigation) in minutes.
[b]Positive responses include both "Yes" and "Maybe with changes" categories.

3.1 | Compliance and Acceptance

A total of 81% (26 out of 32) of the children on the autism spectrum completed the study protocol. All participants completed 7–10 (the maximum) self-reported questionnaires about each gaming session and returned the tablet data. Participants in both groups showed similar total training duration progress (time in the application) as compared to the target time of 300 min (88%; M = 263 min; SD = 103 min; range = 120–432 min for RW and 100% for FB; M = 327 min; SD = 132 min; range = 58–635 min), $W = 113$, $p = 0.15$, adequately meeting the target of 300 min training over 2 weeks. Despite these similarities, we found that the amount of cumulative play time was lower for the RW group compared to FB, as indicated in Table 2 ($p = 0.014$). This imbalance resulted from more time required to navigate menus in RW than in FB. The cumulative play time was 72% of the logged training duration in RW and 86% in FB. Training duration was strongly and positively correlated with the cumulative play time, $r(24) = 0.98$, $p \leq 0.0001$, suggesting both variables reliably measure training dose.

Tapping rate refers to the cumulative number of finger taps recorded within each game, divided by cumulative training in minutes, and was used as an index of motor engagement. Comparable amounts of motor movement were observed between games, as shown by similar tapping rates of training between games ($p = 0.61$; Table 2). Ratings of enjoyment ($p = 0.23$) and sense of difficulty ($p = 0.67$) were comparable for both games and above the medium range. When participants were asked if they would recommend the game, more than two-thirds of the participants in each group responded positively, and the distribution of responses was similar between games ($p = 0.49$).

Both groups played a comparable number of sessions, averaging 5 per week per game. Figure 3 shows the evolution of enjoyment and perceived difficulty over the sessions for both games.

Session adherence and gameplay duration were supported by both logged performance data and parental reports, which showed high correspondence. Only two parents reported helping their child during gameplay, and this was limited to encouragement. These findings suggest that the training was feasible to implement independently at home for most participants.

3.2 | Rhythmic Performance

Table 3 shows the rhythmic performance at both time points (pre- vs. post-training) on individual tasks of BAASTA and the BTI.

When considering the BTI, a composite score capturing the general capacity to track a beat, a positive effect of the training condition, $t(17) = 2.71$, $p = 0.015$, was found for those who played the RW game compared to those who played the FB game (see Table 3). The model intercept was significant, $t(17) = 3.69$, $p = 0.002$, and because RW was coded as 0 and FB as 1, this finding indicates that the increase in the BTI after the training was greater than 0 in this model. The interaction term between cumulative play time and training condition was on the margin of statistical significance ($p = 0.06$), suggesting a different relationship across experimental conditions between training duration and changes in the BTI. The other interaction terms in the model involving the experiment conditions (Game Played * Degree of Autistic Traits and Game Played * Cumulative Play Time * Degree of Autistic Traits) were not significant ($p > 0.11$). The omnibus model (Difference score = 1 + game Played * Cumulative Play Time * Degree of Autistic Traits) provided an overall good fit, $F(7, 17) = 2.36$, $p = 0.07$, $R^2 = 0.49$, with a small effect size ($\eta^2 = 0.02$) for the training condition main effect and large effect size for the cumulative play time and training interaction ($\eta^2 = 0.23$). To assess whether the positive impact of the rhythmic training was linked to the individual amount of training, we tested the relation between cumulative play time and rhythmic improvements (see Figure 4B). For RW, cumulative play time was strongly and positively correlated with improvement in the BTI, $\tau = 0.62$, $p = 0.003$, $n = 13$, but not for FB ($p = 0.77$).

For paced tapping to music, a positive effect of the training condition, $t(15) = 2.83$, $p = 0.013$, was found for those who played the RW game (difference score, M = 0.14, SD = 0.17) compared

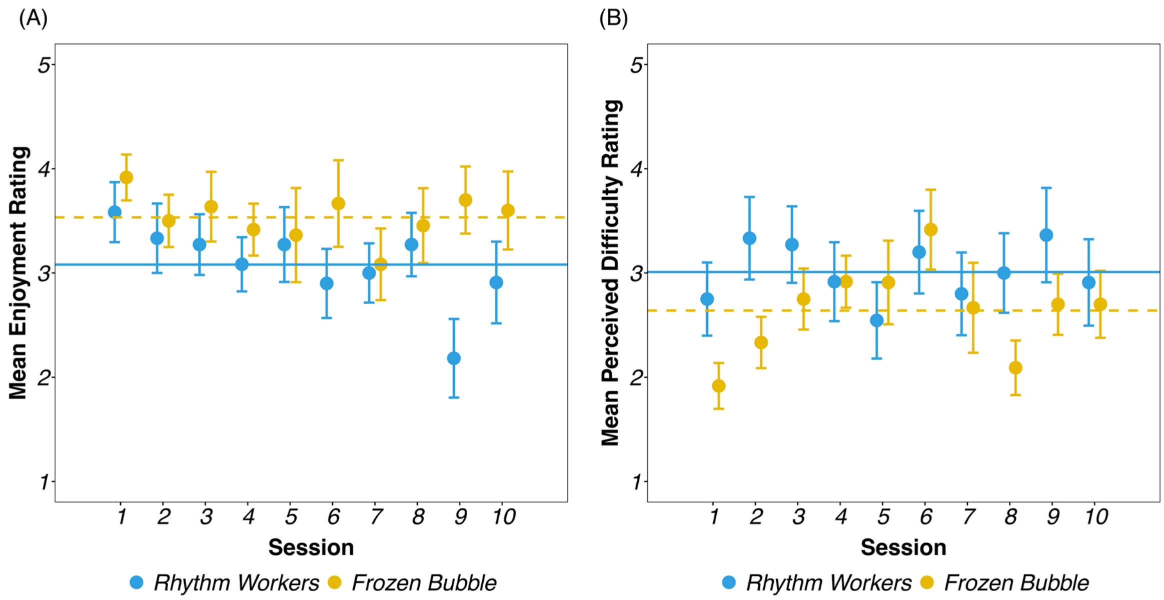

FIGURE 3 | Mean enjoyment (A) and perceived difficulty over the sessions (B) for Rhythm Workers and Frozen Bubble. Error bars indicate SEM, and horizontal lines represent the means across sessions.

TABLE 3 | Rhythmic performance of children with autism after training.

Rhythmic domain		Rhythm Workers					Frozen Bubble					p[a]
		N[b]	Mean	SD	Min	Max	N[b]	Mean	SD	Min	Max	
Beat Tracking Index[c]	*Pre*	13	−0.01	0.88	−1.83	1.31	13	0.19	0.60	−1.07	0.87	0.58
	Post	13	0.22	0.85	−1.47	1.18	13	0.28	0.85	−1.31	1.06	0.80
	Δ[d]	13	0.22	0.47	−0.53	1.08	13	0.09	0.51	−0.94	0.72	**0.015**[e]
Paced tapping to music[f]	*Pre*	13	0.53	0.31	0.13	0.97	12	0.64	0.22	0.27	0.89	0.38
	Post	13	0.67	0.29	0.15	0.97	12	0.72	0.26	0.18	0.95	0.73
	Δ[d]	13	0.14	0.17	−0.14	0.45	11	0.09	0.14	−0.15	0.34	**0.013**[e]
Paced tapping to metronome[f]	*Pre*	13	0.68	0.23	0.23	0.90	13	0.80	0.07	0.68	0.93	0.36
	Post	13	0.70	0.24	0.25	0.91	13	0.76	0.14	0.44	0.90	0.96
	Δ[d]	13	0.02	0.11	−0.17	0.22	13	−0.04	0.14	−0.37	0.20	0.67[e]
Rhythm perception A'	*Pre*	13	0.86	0.16	0.34	1.00	12	0.84	0.17	0.44	1.00	0.98
	Post	13	0.84	0.13	0.50	0.97	13	0.84	0.19	0.44	1.00	0.33
	Δ[d]	13	−0.12	0.86	−1.96	1.93	12	−0.03	0.44	−1.24	0.33	0.16[e]

Note: $p < 0.05$ is indicated in bold.
[a]Wilcoxon rank sum test p value.
[b]N varies due to missing data for some participants who could not complete all the tasks because of task difficulty (e.g., tapping in antiphase or double-time) or task-specific inattention.
[c]Averages based on z-scores.
[d]Change scores.
[e]p value of the main effect of the Game Played in linear model.
[f]Synchronization consistency scores (vector length).
Difference score = 1 + Game Played * Cumulative Play Time * Symptom Severity.

to those who played the FB game (difference score, M = 0.09, SD = 0.14). We also observed within-group improvement for RW, as indicated by a significant model intercept, $t(15) = 4.86$, $p \leq 0.001$. The other interaction terms in the model were not significant ($p > 0.13$), and the omnibus model provided an overall good fit, $F(7, 15) = 2.64$, $p = 0.06$, $R^2 = 0.55$ with a small effect size ($\eta^2 = 0.014$) for the training condition main effect and a large effect size for the cumulative play time and training interaction ($\eta^2 = 0.22$). The omnibus models for metronome tapping and rhythm perception were not statistically significant ($p > 0.13$).

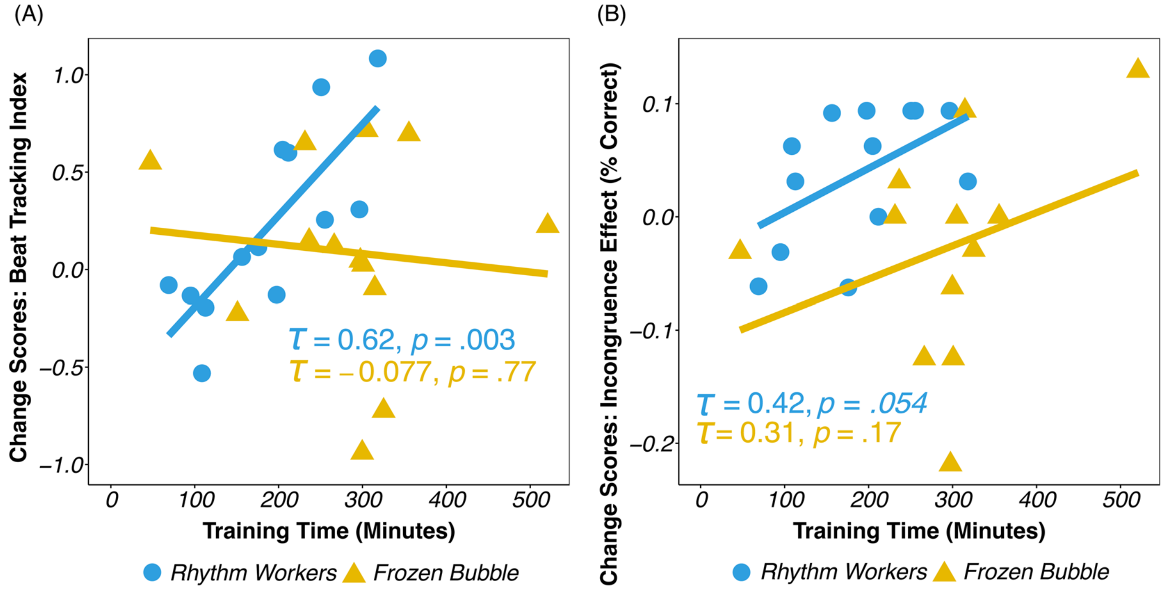

FIGURE 4 | Relationship between training dose and improvement (difference scores) by game condition on the Beat Tracking Index (A) and the incongruence effect (% correct) of the Flanker task (B).

3.3 | Executive Functioning

Table 4 shows the executive functioning performance at both time points, the change scores on individual tasks, and the executive functioning index.

In the executive functioning index for accuracy (proportion of correct responses), a positive effect of the training condition was found for those who played RW compared to those who played the FB game (see Table 4), $W = 125$, $p = 0.02$, with a moderate effect size, $r = 0.41$. We also observed that the improvement for RW was greater than 0, $V = 86$, $p = 0.001$, but not for FB ($p = 0.55$). For RW, cumulative play time was strongly and positively correlated with improvement in the incongruence effect (% correct) of the Flanker task (Figure 4) and was on the cusp of statistical significance $\tau = 0.42$, $p = 0.054$, $n = 13$, but not for FB ($p = 0.17$). There was no difference between games in the executive functioning index for speed (proportional reaction time; $p = 0.96$).

3.4 | Degree of Autistic Traits

To test whether the positive effect of rhythmic training is associated with the degree of autistic traits, we explored the relationship between individual differences in global and subcomponent autistic characteristics using the Social Responsiveness Scale (SRS-2) and changes in rhythmic and executive functioning after training between games (Figure 5).

The total T-scores of the SRS-2 were negatively correlated with the change in executive functioning accuracy in the RW group and at the margin of statistical significance, $\tau = -0.41$, $p = 0.07$, $n = 11$, but not in FB ($p = 0.62$). The total T-scores of the SRS-2 were not correlated with improvement on the BTI for either group ($p > 0.18$). We explored relationships with subcomponents of the SRS-2 and outcome improvement to inform future hypothesis generation. Social awareness scores (higher scores means stronger autistic traits) before training were positively correlated with improvement in beat tracking in RW, $\tau = 0.52$, $p = 0.022$, $n = 12$, but not in FB ($p = 0.46$), independent of playing time ($\tau = 0.36$, $p = 0.11$) and motor movement (tap rate: $p = 0.77$). Restricted interests and repetitive behavior scores before training were negatively correlated with improved executive functioning accuracy, $\tau = -0.60$, $p = 0.007$, $n = 11$, but not in FB ($p = 0.99$). Restricted interests and repetitive behavior scores before training were negatively correlated with the maximum level reached in RW (game progress); however, they were on the cusp of statistical significance, $\tau = -0.42$, $p = 0.06$, $n = 11$. All other SRS-2 subscales were examined but did not show significant or consistent associations with rhythmic or executive change scores (all $p > 0.10$) and are, therefore, not reported in detail.

4 | Discussion

To adapt a rhythm-based rehabilitation tool for autistic children, we investigated the feasibility of comparing a rhythmic training game (RW) with a nonrhythmic active control game (FB) on measures of rhythmic performance (perceptual and motor) and executive functioning. This at-home protocol used mailed tablets and remote testing procedures and was primarily designed to evaluate the feasibility of the training, including retention, adherence, player engagement, and successful completion of the assessments. As secondary hypotheses, we expected RW training would lead to improvements in rhythmic performance, compared to the control game, and explored whether individual differences in autistic traits moderated training-related changes. We also explored possible training effects on executive functioning.

Beyond outcome measures, specific design features of the rhythm game are also relevant for interpretation. Both RW and FB engage sustained visual attention; therefore, differences between games cannot be attributed to visual stimulation alone. RW introduces a dynamic visuomotor component, as children synchronized their

TABLE 4 | Executive functioning (EF) performance of children with autism after training.

EF domain		Rhythm Workers					Frozen Bubble					p[a]
		N[b]	Mean	SD	Min	Max	N[b]	Mean	SD	Min	Max	
EF index (accuracy)[c]	*Pre*	13	0.08	0.45	−0.66	0.81	13	0.13	1.31	−3.63	1.25	0.16
	Post	13	0.49	0.52	−0.74	1.11	13	0.06	1.15	−2.97	1.06	0.41
	Δ[d]	13	0.41	0.43	−0.10	1.30	13	−0.07	0.60	−1.47	0.67	**0.02**
EF index (speed)[c]	*Pre*	13	0.20	0.47	−0.45	0.84	13	−0.18	0.96	0.27	0.89	0.26
	Post	13	0.32	0.41	−0.39	1.24	13	0.07	0.40	−3.08	0.97	0.15
	Δ[d]	13	0.12	0.58	−1.04	1.10	13	0.25	0.78	−0.90	2.31	0.96
Response inhibition (Go/No-Go A')	*Pre*	12	0.89	0.06	0.77	0.98	13	0.92	0.04	0.84	0.98	0.45
	Post	12	0.92	0.05	0.82	0.99	13	0.93	0.15	0.83	0.98	0.34
	Δ[d]	12	0.02	0.05	−0.06	0.11	13	0.02	0.03	−0.03	0.07	0.40
Incongruence effect (Flanker accuracy)[e]	*Pre*	13	−0.04	0.03	−0.09	0.00	12	−0.04	0.21	−0.69	0.13	0.08
	Post	13	0.00	0.06	−0.09	0.09	12	−0.07	0.17	−0.59	0.03	0.31
	Δ[d]	13	0.04	0.06	−0.06	0.09	12	−0.03	0.10	−0.22	0.13	0.08
Incongruence effect (Flanker speed)[e]	*Pre*	13	−0.06	0.07	−0.24	0.03	12	−0.19	0.23	−0.80	0.01	0.02
	Post	13	−0.07	0.08	−0.22	0.09	12	−0.14	0.12	−0.32	0.00	0.25
	Δ[d]	13	−0.01	0.11	−0.22	0.19	12	0.06	0.19	−0.26	0.52	0.44
Cognitive flexibility effect (accuracy)[e]	*Pre*	12	−0.09	0.07	−0.27	−0.01	13	−0.07	0.09	−0.23	0.10	0.93
	Post	12	−0.09	0.10	−0.23	0.17	13	−0.08	0.07	−0.23	0.02	0.48
	Δ[d]	12	0.00	0.12	−0.16	0.27	13	−0.01	0.10	−0.16	0.14	0.99
Cognitive flexibility effect (speed)[e]	*Pre*	12	−0.52	0.41	−1.14	0.09	13	−0.55	0.39	−1.44	0.08	0.81
	Post	12	−0.43	0.26	−0.97	−0.22	13	−0.45	0.27	−1.01	0.04	0.47
	Δ[d]	12	0.09	0.44	−1.05	0.66	13	0.10	0.33	−0.63	0.65	0.85

Note: $p < 0.05$ is indicated in bold.
[a]Wilcoxon rank sum test p value.
[b]N varies due to missing data for some participants who could not complete all the tasks because of task difficulty (e.g., tapping in antiphase or double-time) or task-specific inattention.
[c]Averages based on z-scores.
[d]Change scores.
[e]Accuracy as measured by the proportion of raw correct responses and speed by the raw proportional reaction time in milliseconds.

taps to a spatially moving visual target. It seems unlikely that this component alone explains the differential effects of the two games, as improvements in rhythmic ability were observed only in the rhythmic training condition, supporting the role of structured rhythmic practice rather than visual engagement per se. A similar pattern was observed for executive functioning outcomes, which improved only in the rhythmic training condition. Because the present study was not designed to isolate the contribution of spatially guided tapping, future work could systematically manipulate moving versus stationary targets within rhythmic training to determine whether this feature modulates engagement or transfer effects.

4.1 | Feasibility of Gamified Rhythm Training in Autistic Children

Our results show high retention, adequate adherence (> 70%), and positive player engagement overall, with comparable levels between both games. Gamified rhythmic training using RW is feasible to implement in autistic children and recommended for further investigation in a more robust randomized control trial. Training with the rhythmic game enhanced rhythmic abilities more than the nonrhythmic game, and promising results for executive functioning were also observed. The specificity of the effect of the training was reinforced by a positive correlation between skill gains and training duration, a finding observed only with the rhythmic game. Observed improvements should be interpreted as preliminary trends within the scope of a feasibility study. This study offers the first demonstration of gamified rhythmic training through a tablet-based serious game as a promising approach to supporting rhythmic skills (perceptual and motor) and executive functioning in children on the autism spectrum.

The study's retention rates show that these interventions can be effectively implemented in real-world settings. Approximately 81% of participants completed the protocol, surpassing typical pediatric mental health study retention rates [62] and at a similar level as ADHD [38]. Participants achieved 88% of the target

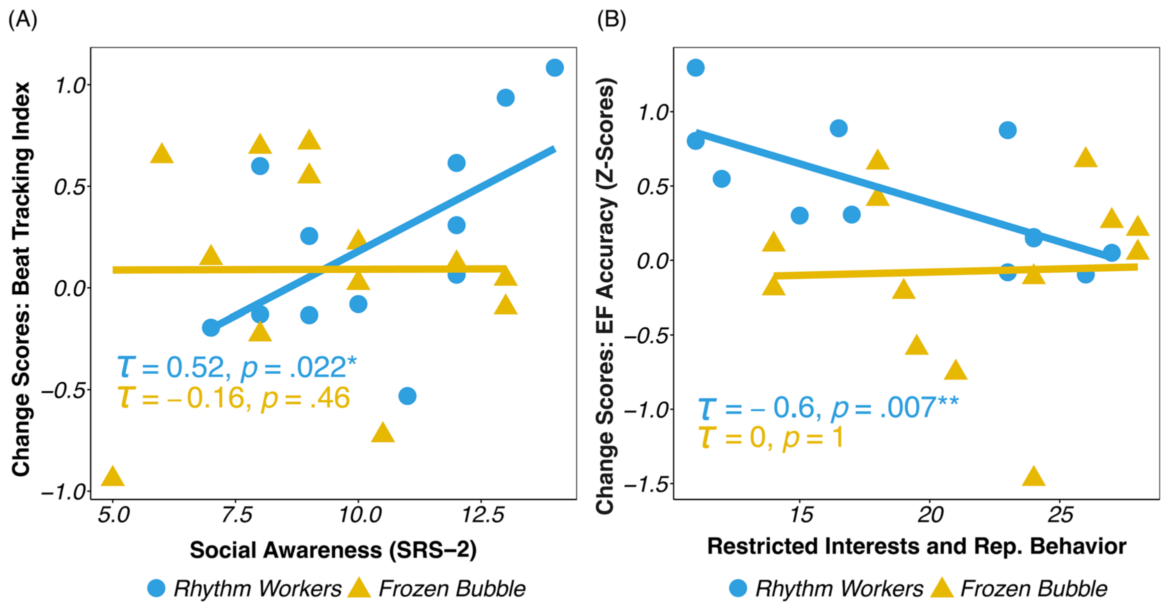

FIGURE 5 | (A) Relationship between social awareness (raw scores) and change scores on the Beat Tracking Index by group and amount of motor movement (total taps) during training, and (B) relationship between repetitive behaviors and restricted interests (raw scores) and change scores on the executive functioning accuracy by game played.

training duration for RW and 100% for FB, showing a strong adherence to the training protocol. In terms of player engagement, participants completed pre-post session assessments (> 90%) and provided feedback on their experience over 2 weeks (~7–10 sessions). They reported comparable enjoyment and perceived difficulty ratings between games. These results suggest that autistic participants would maintain engagement in training programs longer than 2 weeks. Furthermore, FB was validated as an effective control game, sharing key features with RW (e.g., graphics, music, motor demands) while excluding the rhythmic alignment component, ensuring robust causal inferences about the benefits of rhythmic training for larger studies. An active control replicates nonspecific elements (e.g., duration, interaction) but excludes the core training component, isolating mechanisms responsible for the outcomes [72].

4.2 | Benefits on Rhythmic Skills and Executive Functioning

This study provides the first evidence that gamified rhythmic training can support rhythmic skills (perceptual and motor) in autistic children. RW increased rhythmic accuracy (BTI [61]), with no comparable changes observed in the control condition. Time spent on RW positively correlated with rhythmic skill gains. When examining the components of the BTI, observed effects were primarily driven by improvements in music-paced tapping. No significant training-related changes were observed for metronome-paced tapping or rhythm perception, which showed smaller effect sizes and greater variability, likely reflecting baseline differences and limited room for improvement. This pattern is notable, as tapping to music is generally more demanding than tapping to a regular metronome and more closely resembles the synchronization demands of the RW game. Together, these findings suggest that rhythm-based training may preferentially enhance beat extraction and synchronization in ecologically valid musical contexts, a possibility that warrants direct testing in future studies.

Beyond rhythmic improvements, RW moderately enhanced executive functioning, particularly inhibition control accuracy, without compromising response speed. Training duration correlated positively with improved inhibition control, though this trend was on the cusp of statistical significance. Although several individual rhythm and executive functioning measures did not show significant group differences, our primary analyses focused on composite scores that aggregate performance across tasks. This approach reduces measurement noise and better reflects overarching constructs. Analyses of individual task outcomes were exploratory, but tapping to the beat of music and interference control (measured via the flanker task) contributed most strongly to the composite-level effects.

Possible improvements in executive functioning observed following rhythm training may emerge from overlapping demands placed on shared cortico-cerebellar and basal ganglia networks supporting both motor and cognitive timing [73, 74]. Beyond cognitive explanations, the concept of communicative musicality emphasizes rhythm as a foundational structure for intersubjective connection, particularly in early development [75]. While the present study focused on intrapersonal rhythmic skills, future work could investigate whether gamified rhythm-based tools also facilitate attunement to the embodied rhythms of social engagement, such as those involved in interpersonal synchrony and relational timing. Communicative musicality and related forms of social coordination emerge through dynamic, bidirectional rhythmic interaction, which was not directly assessed here. However, prior work suggests that interventions involving rhythmic interaction with another person can influence interpersonal synchrony and social engagement [6]. Extending gamified rhythm training paradigms to explicitly interactive contexts represents an important direction for future research.

4.3 | Exploratory Finding on Individual Differences

Individual differences also appeared to influence training outcomes. While the overall level of autistic traits (as measured by the SRS-2 total score) was not associated with improvements, specific subdomains showed meaningful associations with change. Individual differences in Social Awareness moderated training-related gains in rhythmic performance within the RW group. Specifically, higher Social Awareness scores—reflecting less awareness of social cues—were associated with larger improvements in the BTI (Figure 5A). While engagement-related measures (playing time) showed similar directional associations, the relationship between Social Awareness and BTI improvement cannot be attributed solely to motor output. This pattern was not observed in the FB control group, indicating specificity to rhythm-based training. One possible explanation is that children with greater social-awareness–related difficulties may benefit more from structured, temporally predictable activities that emphasize external rhythmic cues and sensorimotor synchronization. RW provides clear, repetitive temporal structure and minimizes explicit social demands, which may reduce competing cognitive or social load while supporting engagement with timing-related information. In this context, children with higher baseline social-awareness difficulties may have more opportunity for improvement in beat extraction and synchronization skills. Alternatively, greater baseline impairment may be associated with increased responsiveness to training due to larger initial variability or greater scope for change on timing-based measures. These interpretations are not mutually exclusive and should be examined directly in future studies designed to test whether baseline social-awareness profiles predict differential responsiveness to rhythm-based interventions. In contrast, higher baseline restricted interests and repetitive behaviors were associated with smaller executive functioning gains within the RW group, indicating that while rhythm-based training may be particularly beneficial for children with greater social-awareness difficulties, elevated RRB may constrain transfer to executive domains. Together, these findings lay the groundwork for future research programs examining how individual timing profiles and autistic trait dimensions shape responsiveness to rhythm-based digital interventions.

4.4 | Limitations

This study has several limitations that should guide the interpretation of findings. First, autism diagnoses were based on parent report without formal clinical confirmation. While this reflects a community-based recruitment strategy appropriate for feasibility testing and ecologically valid neurodiversity, future studies could use clinically verified diagnoses to confirm findings. Comorbid conditions, such as ADHD, were excluded based on parent self-report, which may have resulted in underreporting. This limits the generalizability of the findings to the broader autistic population, where such comorbidities are common. Nonetheless, the distribution of symptom severity on the SRS-2 supports the characterization of the sample: all but one child scored within the moderate to severe range, providing converging evidence that the participants displayed clinically meaningful traits of autism. The small sample size, short intervention duration, gender imbalance (5:1 compared to the typical 4:1 prevalence), and exclusion of children with common comorbidities (e.g., ADHD) limit the generalizability of the findings. However, as a pilot and proof-of-concept study, such constraints were expected. Finally, no direct observation (e.g., video recordings) was used to verify training fidelity. Future studies could include such measures to better assess engagement. These encouraging feasibility and preliminary outcome data offer a promising foundation for future randomized controlled trials with more diverse and representative samples. Notably, similar patterns of improvement were observed in a parallel study with children with ADHD [38].

4.5 | Future Perspectives

This study benefited from automated gameplay logs, a strength given that most at-home interventions lack objective monitoring. It will also be important to examine the sensory accessibility of gamified tools, as autistic individuals may differ in their tolerance for visual and auditory complexity. Although preliminary gains in rhythm and executive functioning were observed, these should be interpreted cautiously, given the small sample and exploratory design. Weak correlations among executive functioning subcomponents reflect known dissociations in autism [76]. Still, these early signals are encouraging and merit follow-up. Larger, fully powered randomized trials are needed to replicate and extend these findings. Future studies could also directly manipulate game design features, such as the presence of spatially moving versus stationary targets, to determine their specific contributions to engagement, learning, and transfer.

Children on the autism spectrum typically exhibit fewer stable forms of social synchronization, such as difficulty coordinating their movements with others during activities like rhythm games or pendulum swinging [77]. Although our training did not involve direct social interaction, the results suggest that even simple rhythmic tasks like finger tapping may engage underlying mechanisms of social coordination. Temporal synchrony is foundational to joint action, shared attention, and interpersonal synchrony [78, 79], and its disruption has been linked to social-communication differences in autism [14, 80]. By strengthening predictive timing and sensorimotor alignment, rhythm-based activities may thus indirectly support social synchrony without requiring overt social demands—making them particularly suitable for children who experience difficulties in conventional therapeutic settings. This opens promising avenues for inclusive, low-pressure interventions targeting foundational timing skills that underlie broader social and cognitive functions.

Comorbid neurodevelopmental traits should be systematically examined in future trials. Although ADHD diagnoses were excluded based on parent report, autism–ADHD co-occurrence has been reported at ~30% in large samples [47], with broader estimates approaching 50% in some reviews [46]. Given that timing variability and executive control differences are central to both autism and ADHD, co-occurring attentional traits may moderate responsiveness to rhythm-based interventions. Notably, similar improvements using the same protocol have been observed in children with ADHD [38], supporting the possibility that predictive timing mechanisms represent a shared, transdiagnostic target. Future work should directly assess comorbid symptom dimensions and test moderation effects in adequately powered designs.

5 | Conclusions

Auditory rhythm-based training may hold promise for supporting and enhancing predictive timing abilities in individuals on the autism spectrum, where timing profiles are often variable and diverse [14, 27]. This type of training has been shown to enhance motor coordination, attention, and executive functioning, all of which support nonverbal social coordination in autism [80–82].

Parallel work using the same training protocol in a separate sample of children with ADHD has yielded similar improvements in rhythmic performance and executive functioning [38], strengthening the plausibility of the effects observed here. Together, these findings suggest that rhythm-based digital interventions may address overlapping timing and cognitive difficulties shared across neurodevelopmental disorders. Given the transdiagnostic nature of rhythm differences involved in autism, ADHD, and stuttering, gamified rhythmic training may represent a scalable, accessible tool with broad relevance across neurodevelopmental populations more broadly. Future research should directly compare effects across diagnostic groups and explore how individual symptom profiles moderate responsiveness to rhythmic training.

This study demonstrates the feasibility and exploratory potential of gamified rhythmic training for autistic children. Preliminary findings suggest that RW may improve rhythmic, motor, and executive functioning, providing initial, hypothesis-generating evidence of its pragmatic value. The validated control game (FB) ensures that observed effects are attributable to rhythmic training rather than nonspecific engagement factors such as enjoyment ratings, perceived difficulty, and motor engagement. These findings are based on a small-scale study and should be replicated in a larger sample with formal diagnoses. Future research could also include individuals with comorbidities, such as ADHD, to improve the generalizability to autistic people. The present work lays the foundation for future research on gamified approaches for people on the autism spectrum and other neurodevelopmental conditions. While based on a small-scale feasibility study, these findings highlight the potential of rhythm-based digital tools to engage perceptual, motor, and cognitive timing processes across diagnostic boundaries. By demonstrating feasibility and identifying trait-specific moderators of response, this work lays the groundwork for a scalable research program investigating rhythm-based digital tools as candidates for personalized interventions targeting timing and executive mechanisms in autism.

Author Contributions

Kevin Jamey: Writing – original draft, software, resources, project administration, methodology, formal analysis, data curation, conceptualization; Hugo Laflamme: Project administration, methodology, preliminary analysis, writing – review and editing; Nicholas E. V. Foster: Writing – review and editing, validation, software, methodology, formal analysis, data curation, conceptualization; Simon Rigoulot: Writing – review and editing, conceptualization, supervision; Simone Dalla Bella: Writing – review and editing, supervision, conceptualization, funding acquisition.

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Conflicts of Interest

S.D.B. is on the board of the BeatHealth company dedicated to the design and commercialization of rhythm-based interventions, including tools related to the BAASTA battery. However, the version of RW used in this study was a noncommercial, research-only version developed independently for academic use. The study received no funding and only limited input from BeatHealth. Other authors have no competing interests to disclose.

Ethical Consideration

This study was approved by the Comité d'éthique de la recherche en éducation et en psychologie (CEREP) at the University of Montreal (CEREP-20-008-P).

CONSORT Statement

This study adheres to the Consolidated Standards of Reporting Trials (CONSORT) guidelines for reporting randomized controlled trials. Blinding procedures were implemented for assistants administering tests and assessors analyzing outcome measures. Participants were not aware of group assignments (experimental vs. control) due to the hidden nature of the intervention manipulation (synchronizing motor movement or not to the music in the environment). The primary outcome measures included sensorimotor synchronization and executive functioning scores, assessed at baseline and post-intervention. Secondary outcomes included correlations between training duration and improvements on outcome measures. Data were analyzed using an intention-to-treat approach, and all participants who returned equipment and honestly attempted the training and produced traceable logged training data were included in the final analysis. Participant recruitment, retention, and adherence rates were documented throughout the study. Any deviations from the protocol, as well as adverse events, were recorded and reported. Ethical approval was obtained from the University of Montreal (see Ethical Consideration), and informed consent was secured from all participants and/or their legal guardians. This trial was not preregistered on a government website, but the protocol was based on an existing pilot study in children with ADHD (available as a pre-print since March 2024 and presented at the Society for Music Perception and Cognition 2022 conference: https://static.pheedloop.com/media/events/EVETCKUGPTYVI/files/aDZAJDnX_348189.pdf). This work was supported by funding from grant 05453 from the Natural Sciences and Engineering Research Council of Canada (NSERC), grant 115050 from the Canadian Institute of Health Research (CIHR), and grant 0160 from Tier 1 Canada Research Chairs to Simone Dalla Bella, Canada Research Chair in Music Auditory-Motor Skill Learning and New Technologies.

Peer Review

For transparency, the peer review documents associated with this article are available at https://doi.org/10.1111/nyas.70270.

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Supporting Information

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Supplementary Materials: nyas70270-sup-0001-SuppMat.docx